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Original article

Geomorphological conditions of the location historical ironworks. A contribution to the research based on DEM analysis from LIDAR data

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ABSTRACT

The aim of this study was to present the use of the natural elements of the relief of river valleys such as changes in the width of the valley bottom, landforms occurring in the bottom of the valley, differences in height of the valley terraces as favourable for the location of the dam partitioning the bottom of the valley and creating a water reservoir for the requirements of historic metallurgical centres. The research was carried out based on DEM analysis from LiDAR data. Features were chosen in river basins with a rich metallurgical legacy. Analysis of the location of the former ironworks was carried out using Surfer 12 software. Five centres were selected due to the fact that only these are the only centres suitable for research which have survived to this day. Using the shaded relief models and contour coloured maps absolute differences in height between valley levels and other forms of relief occurring in the valley were analyzed, as well as the distribution of individual terrain forms in the designated part of the valley and changes in the width of the valley bottom were analysed in the context of the location of former metallurgical centres. On the basis of the contours of the former water reservoir visible in the valley relief, and using a surface area measurement tool (Surfer software), the range of the area that the reservoir could cover was measured. On the basis of the results obtained, it can be seen that convenient geomorphological conditions were used for the placement of selected weirs and metallurgical ponds which facilitated the damming of the valley. Natural narrowing of the valley bottom, or dunes and hills directly adjacent to the valley floor, were utilised during the construction of the dam. The rivers on which the furnace ponds were constructed are relatively small watercourses, so the weirs created by the constructors are not impressive. Their height is generally in the range of about 2 to 3 metres and their length is from about 120 to 300 metres. Nevertheless, they were effective in allowing sufficient water retention and the creation of furnace ponds with a measured area of about 4.5 ha to about 25 ha.

KEY WORDS: DEM, river valley, former pond, LIDAR data, geomorphological features

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1. Introduction

Historical metallurgical centres based on water power, have emerged over the centuries (during the fourteenth – nineteenth centuries) and functioned in times of difficult, rapidly changing political and economic situations, have often ceased to exist or have been subject to degradation. The reasons for their decline have mostly been due to flooding, fire, uprisings, war, and changes in the economic situation or, finally, the depletion of ore and forest resources. These phenomena also forced constant changes in the production profile and through modernisation (SZOT-RADZISZEWSKA, 2009). For the most part, the remains from former ironworks are often poorly visible traces in the terrain or are mentioned in historical references. The most frequently used technique nowadays for identifying the location of former metallurgical centres is the analysis of historical maps and historical literature. In addition to these classical methods, those that make use of the natural sciences can also be used. According to the methods of natural sciences, we can not only get much more accurate information about the location of an ironworks, but we are also able to research the conditions of its location, and often reconstruct its operation (MALIK ET AL., 2015; RUTKIEWICZ ET AL., 2017). Ironworks and smelters were mainly located in the bottoms of river valleys due to the requirement for access to water. Water was used as a power source that operated water wheels, which in turn powered metallurgical machinery (KRÓL ET AL., 2009). A very important factor in the location of metallurgical centres was also the presence of ore deposits and the availability of forests. Thus, the first ironworks and smelters were located in densely forested areas, near bog iron deposits (ZIENTARA, 1954). When metallurgical activity using the water wheel commenced, there were no advanced tools and construction machinery available, and therefore it should be assumed that the natural conditions of the terrain relief were used to locate metallurgical centres. The first human use of favourable terrain conditions was documented during the location of prehistoric settlements (DOBRZAŃSKA & KALICKI, 2009; DOMAŃSKA ET AL., 2009; FAJER, 2009; GLADFELTER, 1977; GRUSZKA ET AL., 2016; KITTEL, 2005; KITTEL ET AL., 2009; MOLEWSKI & POLIŃSKI, 2009; TWARDY & FORYSIAK, 2011). So far, no studies have been conducted describing the location of metallurgical centres from the point of view of their geomorphological features. The aim of this study was to present the use of the natural elements of the relief of river valleys such as changes in the width of the valley bottom, landforms occurring in the bottom of the valley, differences in height of the valley terraces as features favourable for the location of the dam partitioning the bottom of the valley and creating a water reservoir for the needs of historic metallurgical centres. The research was carried out based on Digital Elevation Model (DEM) analysis from LiDAR data. The analyses did not take into account access to ore and wood for charcoal production.

2. Study area and historical background

Features were chosen in river basins with a rich metallurgical legacy. Initial recognition of the terrain relief was also helpful. Former metallurgical centres were selected in Bobrza (Bobrza river basin), Regolowiec (Mała Panew river basin), Brusiek (Mała Panew river basin), Furmanów (Czarna river basin) and near the town of Kalety (Mała Panew river basin) (Fig. 1). The bottom of the River Mała Panew valley is filled with glacial and fluvioglacial sediments from the Saalian glaciation (WŁODEK, 1976). The nature of these sediments means that alluvium formed as a result of their redeposition is largely developed as various fractions of sands. The Czarna riverbed is composed of Jurassic and Triassic sandstones and Jurassic limestones covered with tills from the Riss glaciation (KONDRACKI, 2000). The bottom of the Bobrza valley is filled with sand and gravel deposits that build river terraces. On the Holocene terrace, peats and alluvial deposits are found locally (RUTKIEWICZ & GAWIOR, 2015). The basin of the River Mała Panew is characterised by the occurrence of aeolian sands on quaternary dunes. In the case of the River Bobrza and the upper Czarna basin, the relief is highly dynamic and synclinal and anticlinal structures dominate (PRAŻAK, 1994). It is worth mentioning that the important limiting factor regarding the counting of an accurate number of objects for the research is the preservation of the remains of the historical metallurgy. Most of them have disappeared. The selected centres are characterized in Table 1.

Fig. 1. Location of the research areas

Table 1. The main characteristics of each river ironworks based on: Król et al., 2009; Globisch, 2004; Malik et al., 2014; Trieste, 1864; Goszyk, 2001, 2004; Szczech, 2001; Sulimierski et al., 1881

Former ironworks	Bobrza	Regolowiec	Brusiek	Furmanów	Near the town of Kalety
Foundation	1598	18th	14th	1830-1835	15th ?
Important historical reference	In 1828, it was planned to make a huge investment and locate a modern metallurgical centre here	In 1804 28 tons of iron bars were produced here by 6 employees and 23 people earned their living working in Regolowiec	From 1768, there was a bloomery and a large newly-built furnace, 30 feet high (about 10 metres)	A maximum of 6700 tons of iron per year was produced here (data for 1898)	The metallurgical pond in this place is mentioned in a document from 1454 as a remnant of an ironworks probably destroyed by the Hussites
The type of material produced	iron	iron	iron	iron	?
Type of furnace used	Large furnance	Finery	Large furmance and Bloomery	Large furnance	?
Type of used fuel in furnace	Charcoal	Charcoal	Charcoal	Charcoal	Charcoal ?
The remains of the ironworks	Apart from the remains of the former weir of the first ironworks, there are building elements of an unfinished investment from the nineteenth century	Wooden piles in the bottom of the valley of the Bziniczka River and the remains of the weir are traces of former smelting settlement	The remains of the ironworks include old canals, the outlines of the reservoir, post-production waste, and a partly preserved weir	At present, the dry reservoir basin and the weir are preserved. The buildings of the former ironworks have also been partially preserved	The remains of the weir are very well preserved
Former smelter pond	yes	yes	yes	yes	yes

3. Materials and methods

The first step in determining the location of former ironworks and smelters was the analysis of historical information from written sources and attempting to find the locations of former ironworks on historical maps (Detailed Map of the Voivodeship of Kraków and the Dutchy of Siewierz, 1: 225 000 – from 1787; Gilly Special Karte von Südpreussen 1: 150 000 from 1803; Reymann Karte eines Theils von Neu oder West Gallizien, 1: 180 000 - from 1797; Heldensfeld-Benedicti Carte von West-Gallizien, 1: 288 000 – from 1808). Data sheets from aerial laser scanning were then obtained as .asc files. LiDAR data (0.2 m spatial resolution) from the Central Office for Geodetic and Cartographic Documentation (CODGiK, Poland). DEMs were created based on the LiDAR data. The key condition for the selection of a chosen metallurgical centre was the presence of clear remains in the relief of the area equating with the former metallurgical activity, such as: a weir damming the bottom of the valley, the basin of a former pond, the occurrence of signs of charcoal burning close by. Then the location of the remains in the terrain relief was compared with its location on historical maps and historical descriptions. In this way, we could be sure that the characteristic elements of the relief are the remnants of a former metallurgical centre depicted on the map and mentioned in the historical description. Five centres were selected due to the fact that only this many centres suitable for research have survived to this day. Using the shaded relief models and contour coloured maps absolute differences in height between valley levels and other forms of relief occurring in the valley were analyzed, as well as the distribution of individual terrain forms in the designated part of the valley and changes in the width of the valley bottom were analysed in the context of the location of former metallurgical centres. For selected locations, transverse terrain profiles were created to illustrate the diversity of the relief of the selected area. For each location, four cross section lines were laid: the first just behind the weir, the second in the place of a sudden change in the width of the valley bottom, the third more or less in the middle of the former metallurgical pond and the fourth at the back of the former pond. The profiles were made that way in order to make the best presentation of the use of the variation in the valley floor morphology. All analyses were carried out using Surfer 12 software. On the basis of the contours of the former water reservoir visible in the valley relief, the range of area that the reservoir could cover was measured using the surface area measurement tool in the Surfer software.

4. Results

4.1. Former ironworks in Bobrza

From the shaded relief model of the Bobrza valley, the location of the ironworks is visible in the section behind the gorge (Fig. 2). A weir was built in the place where the hill immediately behind the gorge directly borders the floor of the valley. Based on the profile A-B (Fig. 3), it can be seen that the width of the valley floor here is about 270 m. From the next profile C-D, we note that the width of the valley floor increases and reaches approximately 350 m. The profile E-F illustrates the place of the most extensive part of the valley floor, where the width is about 450 m. This large natural area created a place where the river water could accumulate to form a pond for the ironworks. The example of the profile G-H shows that the width of the valley bottom again decreases to approximately 300 m (Fig. 3). The advantage of this location is to limit the backwater effect. At present, a 150 m long fragment of the weir has been preserved. The current height of the preserved part of the weir is about 2 m and its width is about 15 metres (Fig. 12). Based on the analysis of digital data in the Surfer program, the surface of the ironworks' pond resulting from the damming of the river valley, covered about 25 ha (Fig. 2).

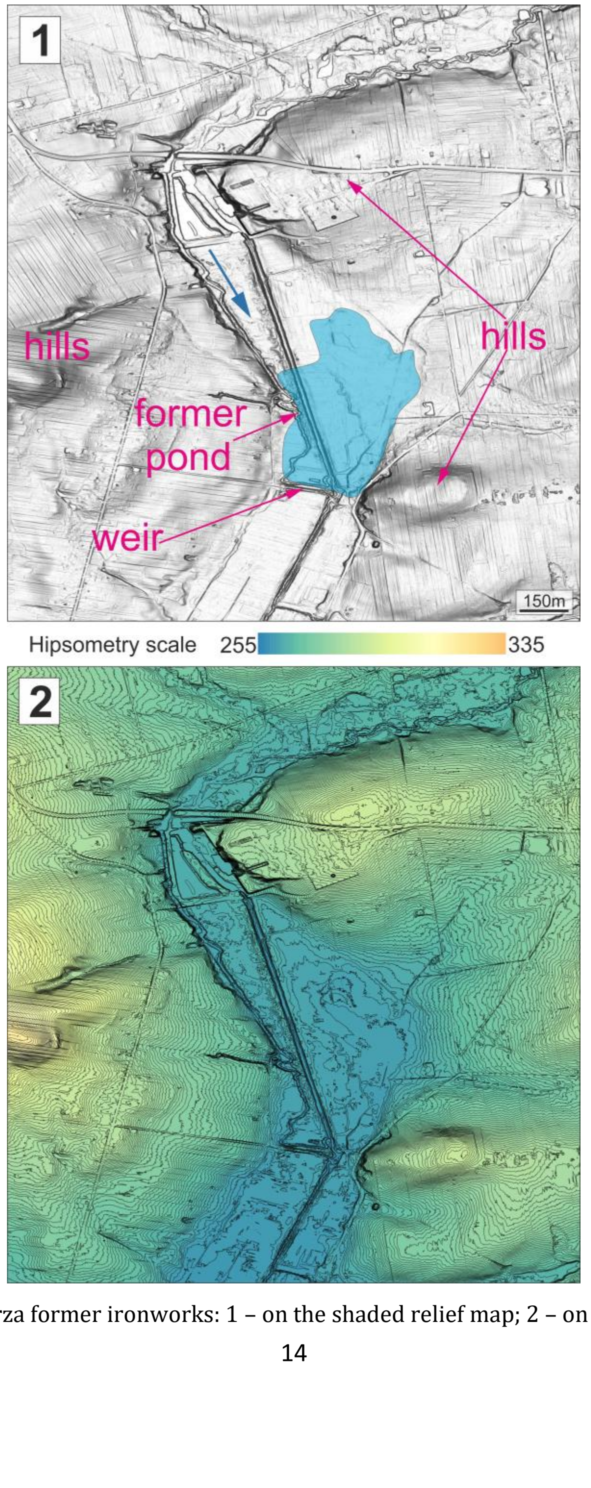

Fig. 2. Location of the Bobrza former ironworks: 1 – on the shaded relief map; 2 – on the coloured contour map

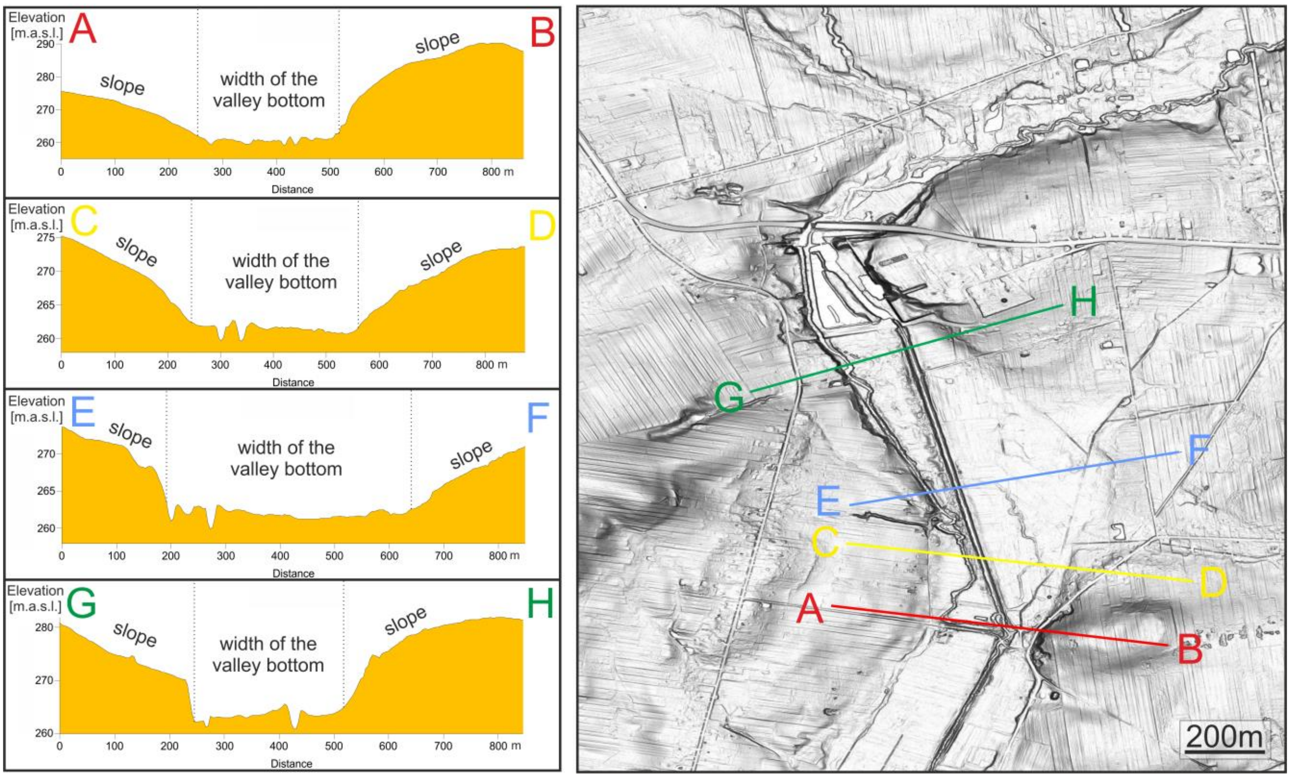

Fig. 3. Location of the Bobrza former ironworks on the shaded relief map with cross section lines representing valley relief indicated

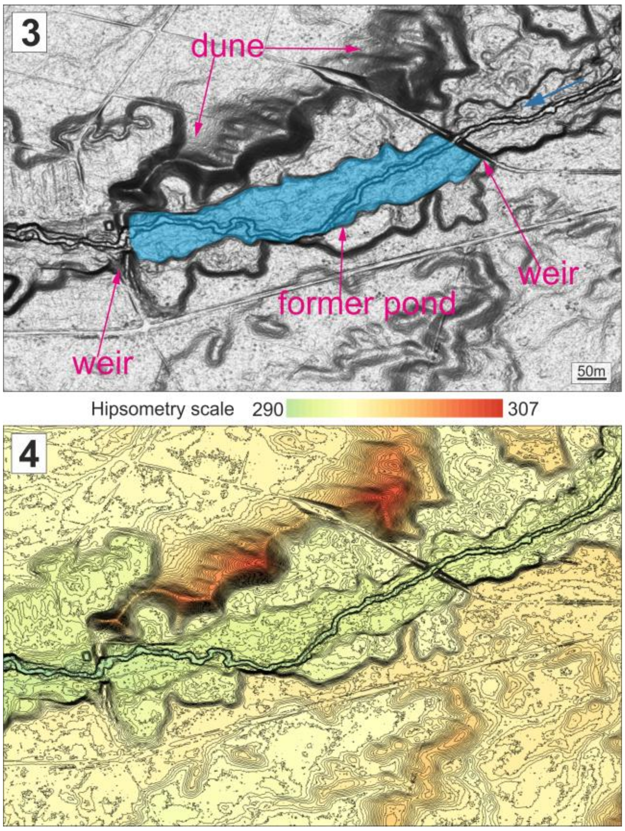

Fig. 4. Location of the Regolowiec former ironworks: 3 – on the shaded relief map; 4 – on the coloured contour map

4.2. Former ironworks in Regolowiec

The metallurgical centre in Regolowiec was located in a section of the valley where there is a clear narrowing of the valley floor by the highest level of the river terrace and a dune is formed on the terraces and flood plain (Fig. 4). The narrowing of the valley floor to a width of about 80 m is visible on the profile I-J. On the profiles K-L and M-N one can see an increase in the width of the valley floor. These valley floor widths are 100 and 150 m respectively. The profile O-P reveals a reduction in the width of the valley floor to about 100 m (Fig. 5). An additional weir was created in this section of the valley. The slopes of the dune dominate on the right side of the stream in the section of the selected valley. Before the renovation that took place to create the existing reservoir, there was a section remaining of the former weir about 80 m long (Fig. 4). The height of the weir before renovation was 3 m (Fig. 12). Based on the analysis of digital data in the Surfer 12 program, the area of the former metallurgical pond was calculated to be about 4.5 ha (Fig. 4).

4.3. Former ironworks in Brusiek

The metallurgical centre in Brusiek was located in a place where the valley floor was narrowed by high terraces. The weir, which originally was about 150 m in length (Fig. 6), was created in this location. According to the profile R-S, the valley floor behind the weir is about 100 m wide. Upstream of the weir, the floor of the valley clearly expands, which creates good conditions for the accumulation of river water. According to the profile T-U, the width of the valley floor in this location is approximately 300 m. The profile W-X illustrates the gradual decrease in the width of the valley floor, in this location it is less than 200 m wide. The last profile Y-Z indicates stabilisation of the width of the valley floor to about 200 m. (Fig. 7). The right side of the pond thus created is dominated by a dune formed on the high terrace (Fig. 6). At present, the weir has been transformed into a bridge with an asphalt road. The current height of the bridge is about 2 m. (Fig. 12). Based on the analysis in the Surfer program, the area of the former reservoir was calculated to be about 19.5 ha (Fig. 6).

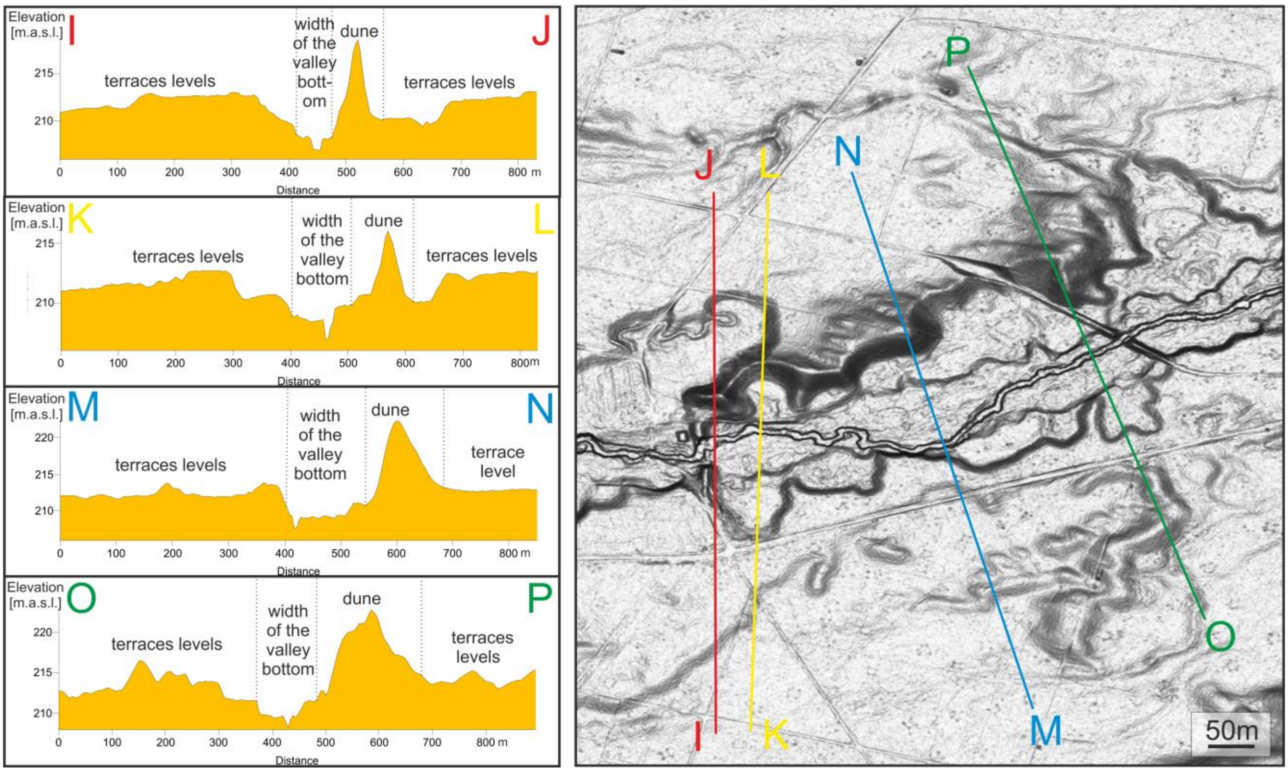

Fig. 5. Location of the former Regolowiec ironworks on the shaded relief map with cross section lines representing valley relief indicated

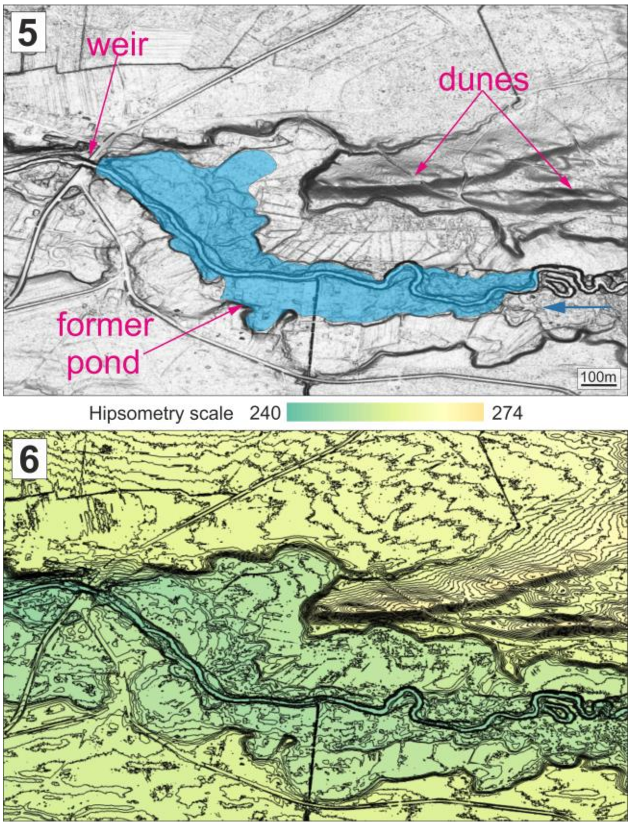

Fig. 6. Location of the former Brusiek ironworks: 5 – on the shaded relief map; 6 – on the coloured contour map

4.4. Former ironworks in Furmanów

A very pronounced narrowing of the valley bottom between its steep slopes was used for the metallurgical centre in Furmanów. There are no visible terracing levels in the morphology of the terrain, but the steep slopes could effectively cause river water accumulation on the flat floor of the valley (Fig. 8). At the location of the profile A'-B' just behind the dam, the width of the valley floor is about 100 m. The profile C'-D' illustrates the gradual increase in the width of the valley floor. It is about 150 m. The profile E'-F' was laid across the most extensive part of the valley floor and has a width of around 360 m. The profile G'-H' illustrates the reduction in width of the valley floor to about 100 m (Fig. 9). Beyond this section, in the place where the valley branches to the source sections of the river, a second, larger weir was created. In order to dam the water of the River Czarna at the chosen location, a dam was created which originally had a length of about 120 m and has now been preserved almost in its entirety (Fig. 8). The current height of the dam is about 2 m from the bottom of the flood plain (Fig. 12). Based on an analysis in the Surfer program, it was calculated that the area of the former reservoir was about 15.5 ha (Fig. 8).

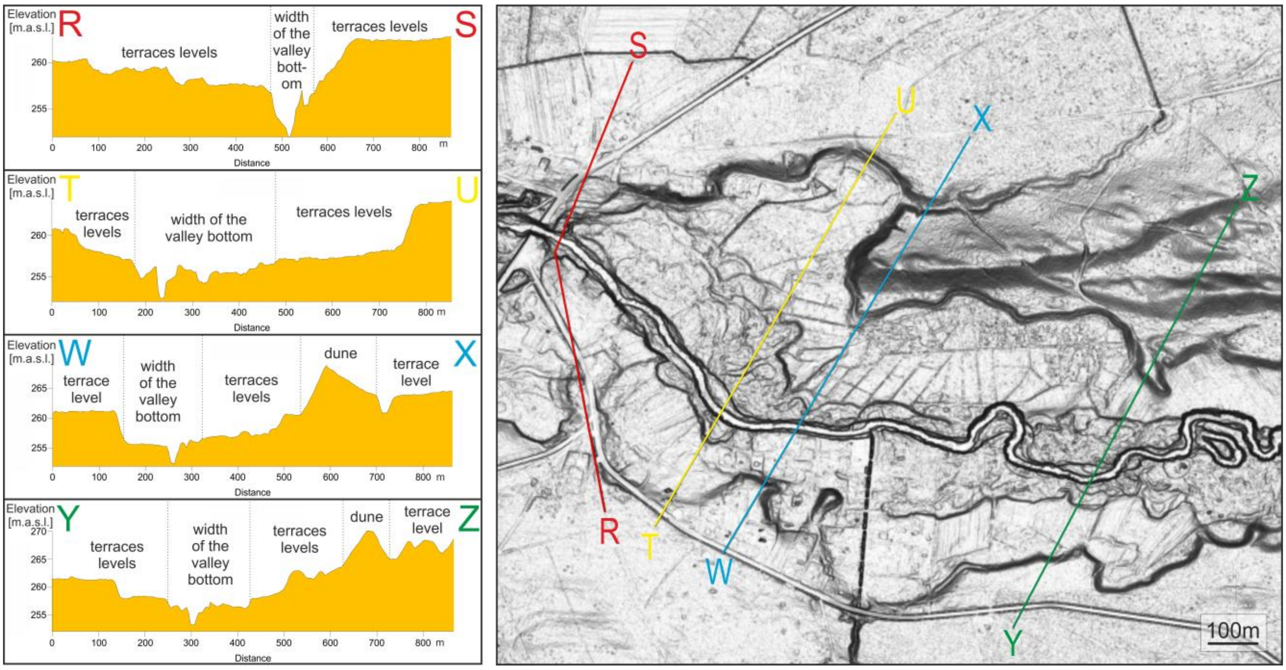

Fig. 7. Location of the former Brusiek ironworks on the shaded relief map with cross section lines representing relief valley indicated

4.5. Former ironworks near Kalety town centre

The presence of dunes bordering the bottom of the valley was used during the construction of a dam and smelter pond near the town of Kalety. The dune occurs on a high terrace on the right side of the stream. The dam was originally about 300 m long. In this case, it is evident that part of the dune was used as a natural barrier damming the water in the bottom of the valley (Fig. 10). This dam is longer than the above-mentioned locations. It continues to the higher parts of the high terrace. The profile I'-J', laid behind the dam, illustrates a valley floor width of about 150 m. The change in width of the valley floor is presented on the profile K'-L'. It is less than 300 m here. The profile M'-N' shows a gradual decrease in the width of the valley floor to about 200 m. The last profile O'-P' shows a reduction in the width of the valley floor to around 100 m (Fig. 11). To the rear of the former reservoir, a smaller dam was formed (Fig. 10). The main dam has almost entirely survived to modern times. Currently, there is about a 20 metre gap through which the river flows. The current height of the dam is about 3 m (Fig. 12). Based on the analysis in the Surfer program, it was calculated that the surface of the former pond was about 10.5 ha.

5. Discussion and conclusions

The first metallurgical centres in the territory of present-day Poland were primitive furnaces known as bloomeries. They were relatively easy to construct but did not allow for high production capacity and they lasted for only a few smeltings. The increasing demand for iron products led to the need to use more advanced production technology (LUDEMANN, 2010). The constructors began to build structures using water power and constructed suitable furnaces and machinery. The power used for driving the metallurgical machinery required the storage of appropriate amounts of water. One of the most important elements from that time was a weir and a furnace pond. The water was accumulated by building a weir and damming the river valley (GOSZYK, 2004). Initially, the founders' skills allowed them to build the dams necessary to operate one water wheel. This type of plant disappears in the fourteenth-fifteenth century. They quickly began to build dams which provided enough water for more water wheels, three water wheels being the standard (PAZDUR, 1964). For this, the role of experienced metallurgists was needed which were imported to Poland from abroad. Thus, whole clans of metallurgists came to Poland, and they established metallurgical centres and developed the industry, e.g. the Caccia family, invited to Poland in the 16th century from northern Italy (Bergamo) (KRÓL ET AL., 2009). In addition, historical sources also indicate the metallurgical activity of the Gibboni and Collonna families in Poland.

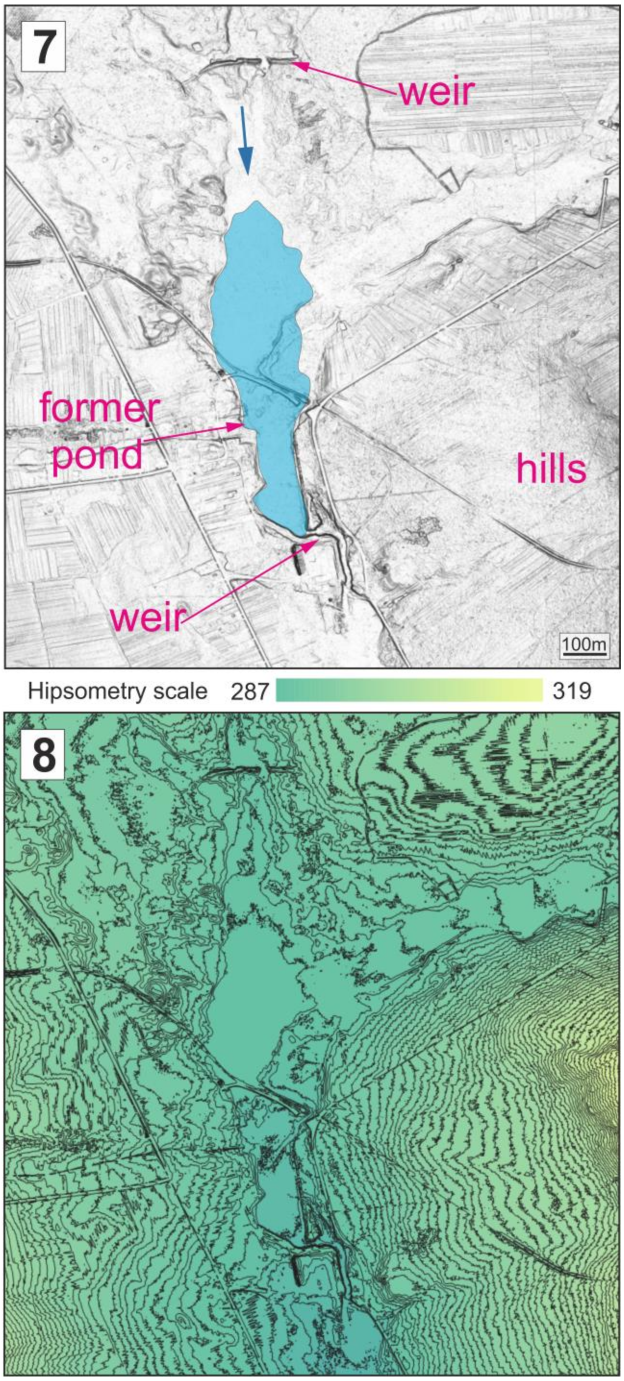

Fig. 8. Location of the former Furmanów ironworks: 7 – on the shaded relief map; 8 – on the coloured contour map

Some of the centres investigated were formerly in the territory of both Germany and the Czech Republic. Therefore, it should be assumed that it was Czech and German specialists who also founded some of the metallurgical centres. Historical references are found regarding the moment of establishment, operation and the ownership structure, but there is no consistent information on how to construct weirs and create metallurgical ponds. There is no description of the methodology, the procedures or the techniques used. Historical descriptions of old metallurgical centres do not provide us with information about the criteria for selecting the right locations where a weir and metallurgical pond could be established. That is why the methodology used in environmental research is so important and valuable at this point, especially since the advanced geoinformatic methods currently used allow one to understand the behavioural process used by the former steelworkers when constructing weirs and ponds.

On the basis of the results obtained, it can be seen that convenient geomorphological conditions were used during the placement of selected weirs and metallurgical ponds which facilitated the damming of the valley. In order to create a dam to retain water, a weir was built in the narrowest possible part of the valley or floodplain. Natural narrowing of the valley bottom or dunes and hills directly adjacent to the valley floor were utilised during the construction of the dam. The rivers on which the furnace ponds were constructed are relatively small watercourses, so the weirs created by the constructors are not impressive. Their height is generally in the range of about 2 to 3 metres and their length is between 120 to 300 metres (Fig. 12). Nevertheless, they were effective in allowing sufficient water retention and the creation of furnace ponds with a measured area of about 4.5 ha to about 25 ha. The measured areas of the ponds are marked by a light blue colour on the shaded relief maps (Fig. 2, 4, 6, 8, 10). In all the cases presented, the weir was located in the place where there was most significant narrowing of the valley bottom and in many cases adjoined forms (dunes or hills) rising above the level of the valley floor. A dune creates favourable conditions for limiting the outflow of waters from this area. In some cases, the slopes of the dunes constitute a natural barrier for the reservoir created. Coloured contour maps very clearly reveal the differences in height between the forms of valley relief and the bottom of the valley. This is particularly well seen in the case of the metallurgical centre in Regolowiec (Fig. 4). On this basis, we can say that there was a lot of intuition in the spatial planning of the constructors of ironworks in those times. Such use of geomorphological features certainly allowed them to shorten the time of the works in relation to the construction of the weir.

Apart from the main weir in the front part of the pond, in some cases a smaller dike located in the back of the former reservoir is visible in the relief (Figs. 4, 8, 10). This was a construction to prevent the pond water from regressing and thus protecting against sudden fluctuations in the water level. It could also prevent a sudden inflow of flood waters and thus indirectly protect the main dam from rupture. In the case of the former ironworks in

Furmanów, a dam built to the rear of the pond was larger than the main dam, which was to protect against a dynamic inflow of water from the headwater area during heavy precipitation (Fig. 8). On the basis of the cross sections through a section of the valley where the former metallurgical pond was located, the detailed relief of the valley floor was exposed. In all cases, it can be seen that the width of the valley floor just upstream of the dam is the smallest on the selected section. This created favourable conditions for the location of the weir.

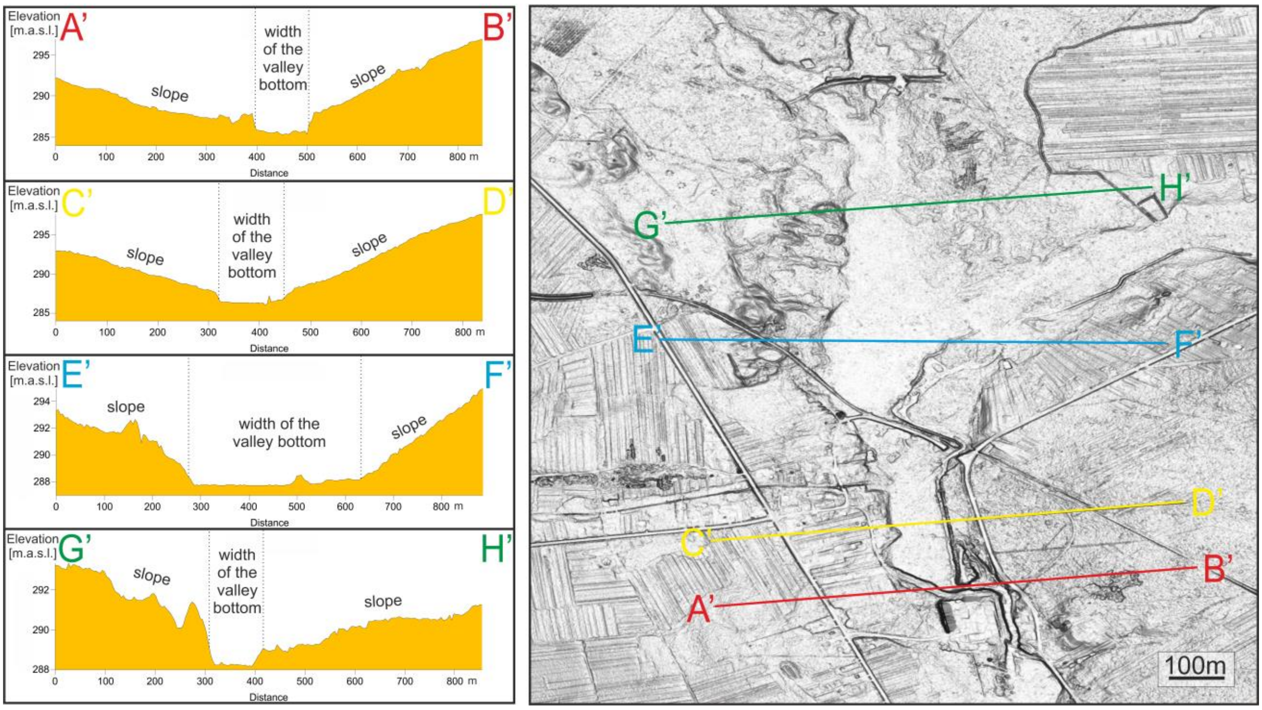

Fig. 9. Location of the former Furmanów ironworks on the shaded relief map with cross section lines representing valley relief indicated

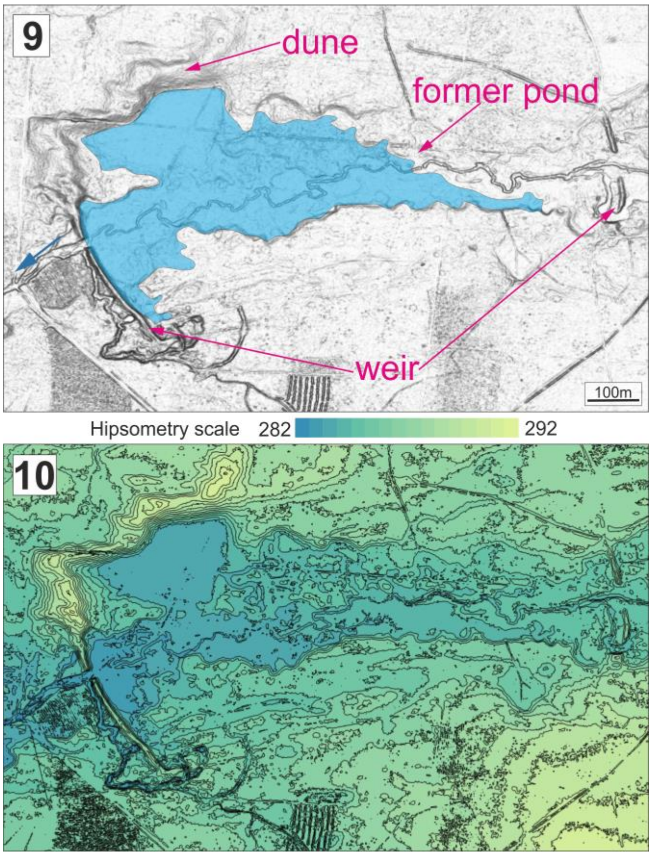

Fig. 10. Location of the former ironworks near the town of Kalety: 9 – on the shaded relief map; 10 – on the coloured contour map

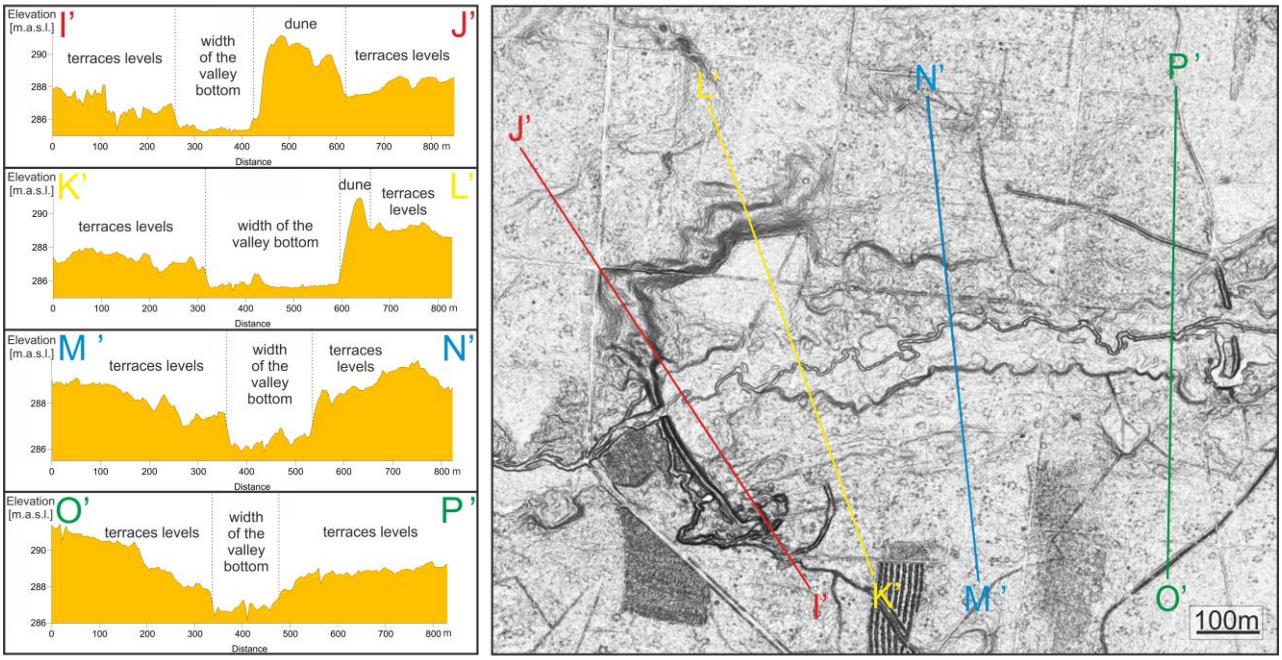

Fig. 11. Location of the former ironworks near the town of Kalety on the shaded relief map with cross section lines representing valley relief indicated

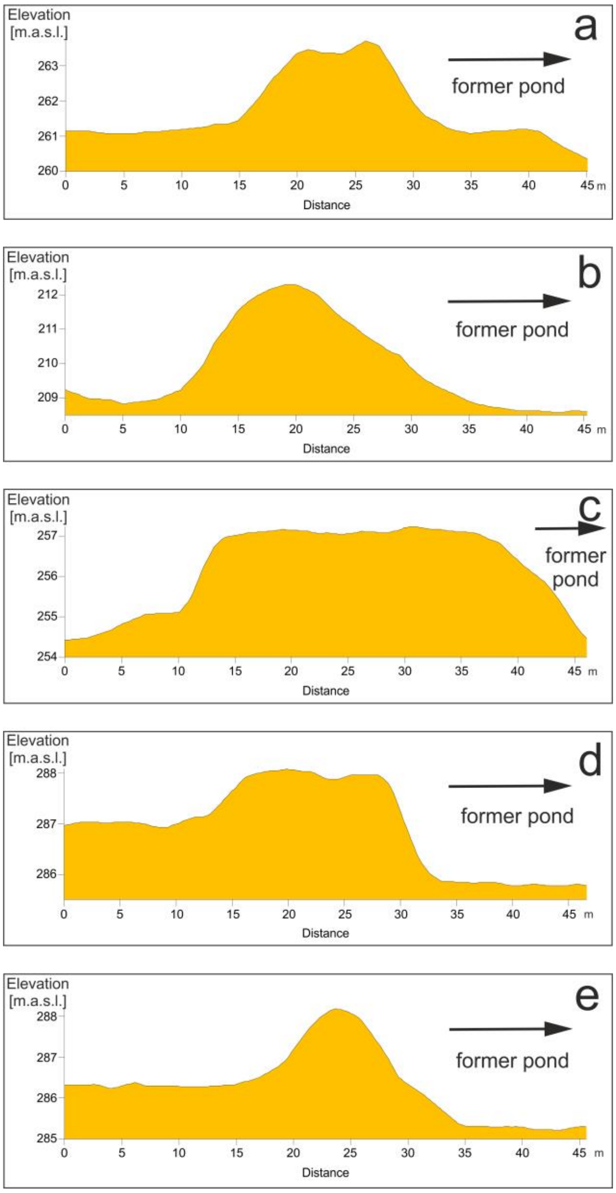

Fig. 12. Cross sections of the main weir in the former ironworks selected: a – Bobrza; b – Regolowiec; c – Brusiek; d – Furmanów; e – near the town of Kalety

On the example of the next two profiles, it is noticeable that the width of the valley bottom increases. In some cases, the change in the width of the valley bottom is gradual and in some cases is rapid. In this part of the valley, the water of the reservoir could have accumulated, spreading over a relatively wide area. From the fourth profile, a clear decrease in the width of the valley bottom is visible in almost all cases.

Through the use of geomorphological conditions, man has contributed not only to the creation of water retention sites but also to changing the profile of the longitudinal flood plain and compensating for the gradient in the locations where the reservoirs were created. This was due to the activation of natural sediment accumulation processes at the bottom of the basin of the reservoir, as well as to local erosion, most often in the zone below the dam. These are the processes commonly recorded in this type of development in the bottom of a river valley (FAJER, 2003; PODGÓRSKI, 2009; RUTKIEWICZ & GAWIOR, 2016). In the period from the fourteenth to the 19th century, the damming of valley bottoms and the creation of ponds for both mills and ironworks and for fish-rearing was a common phenomenon, e.g. in the Liswarta basin in the first half of the eighteenth century alone there were 142 ponds accompanying hydrotechnical objects (FAJER & WAGA, 2002); in the basin of the Czarna between the 16th and the 19th centuries, there were 250 various types of metallurgical plant using water energy (CHŁOPEK, 2015); in the basin of the Mała Panew from the 14th to the 19th centuries there were at least 56 large metallurgical centres using water reservoirs to power the water wheels (MALIK ET AL., 2015).

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